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Advanced Battery Management Challenges for Military Vehicles

Dave Skalny and James Mainero
Energy Storage Team – TARDEC

December 6, 2013

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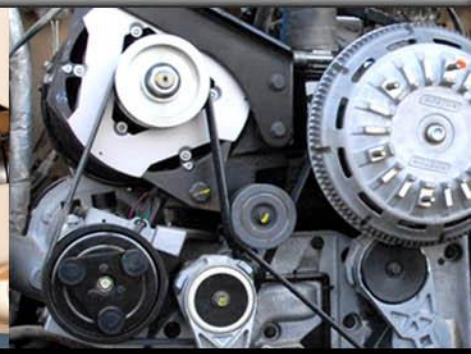

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TARDEC Energy Storage Team Goals, Mission, & Role Commercial vs. Military Requirements Military Shock & Vibration Requirements Battery Management in Military Vehicles Lead Acid BMS Li-ion BMS Conclusions

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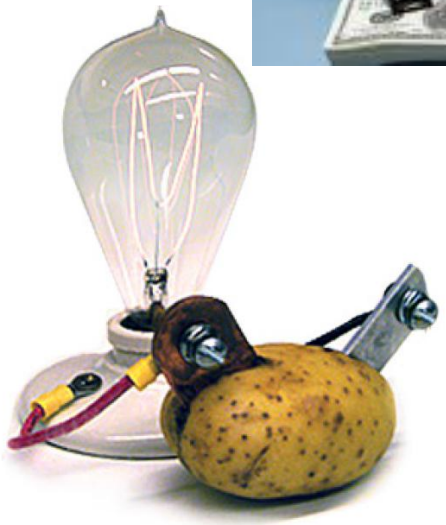
Overview

- TARDEC Energy Storage Team Goals, Mission, & Role
- Commercial vs. Military Requirements
- Military Shock & Vibration Requirements
- Battery Management in Military Vehicles
- Lead Acid BMS
- Li-ion BMS
- Conclusions



Energy Storage Goals and Mission

Energy Storage Goals

- Develop **safe, reliable and cost** effective energy storage systems
- Reduce **battery weight & volume burden** (Increase Energy & Power Density)
- Reduce logistics and fuel burdens
- Extend **calendar and cycle life**

Energy Storage Mission

- **Develop** and **mature** advanced ES technologies for transfer to vehicle platforms
- Test & evaluate ES technologies for prequalification and to **assess TRL (Technology Readiness Level).**
- Identify **technology barriers** and develop technical solutions
- Be recognized as the team of experts in ES components and systems
- Provide technical support to customers, other teams and government agencies for all ES requirements
- Provide **cradle-to-grave** support for all Army ES systems

TARDEC's Role in Army Batteries

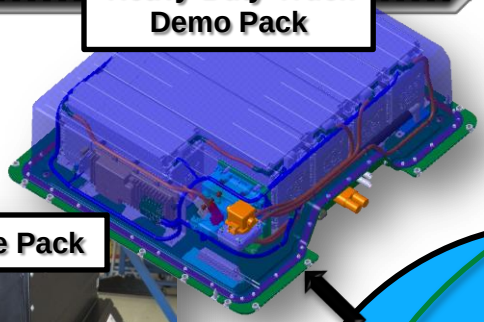
The TARDEC Energy Storage Team is the single point of accountability to provide full service lifecycle engineering and integration support (cradle-to-grave) for Energy Storage systems for Army Ground vehicle platforms.

- TARDEC Energy Storage Team Role is the Engineering Support Activity (ESA) to ensure conformance with the specification & recommendation for QPL acceptance.
- TARDEC Standardization Team Role is the Qualifying Activity that maintains the modifications to the MIL-PRF 32143B and QPL.

- ✓ First Article in-house Testing & Qualification Test Issues
- ✓ Develop, publish, and maintenance of battery standards and performance specifications
- ✓ Participate with DLA on audits of production facilities
- ✓ Establish vendor qualification criteria
- ✓ Provide technical expertise on energy storage systems for all stakeholders
- ✓ Project Management
- ✓ Preparing and updating Tech Manuals
- ✓ Provide SMEs for Analysis of Alternatives (AOAs)
- ✓ Provide sustainment and fielding support of batteries
- ✓ Research, develop, and mature advanced energy storage technologies for enhanced capability
- ✓ Establish and leverage collaborative projects, battery working groups, MOUs/MOAs with other government agencies

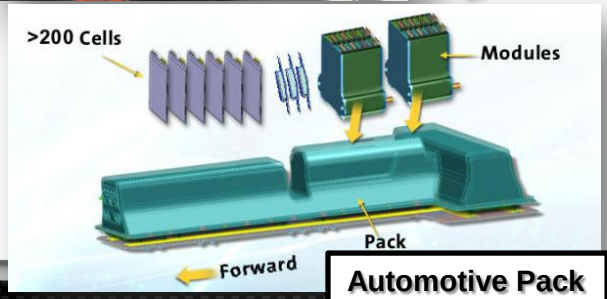
Commercial vs. Military Energy Storage Requirements

Heavy Duty Truck Demo Pack



Automotive Pack

Automotive Pack



Automotive Pack

Divergence of Military and Commercial Requirements:

Extreme *operating environments*

Customer specific forms

Commercial Focus

- Fuel Economy/Hybridized vehicles
- Increased energy – EV applications
- Increased power – HEV applications
- Cost ($250/kWhr)
- Life (cycle/10-15 year calendar life)
- Safety
- SAE Standards
- Operation from to -20^{0}C to +55^{0}C

Military *Requirements*:

- ✓Operating Temperatures: **-46ºC to 71ºC**
- ✓Storage Temperatures: **-54ºC to 88ºC**
- ✓Electromagnetic Interference: MIL-STD-461F
- ✓Ballistic Shock: MIL-STD-810G
- ✓Live Fire: MIL-STD-810G
- ✓Explosive Environment: MIL-STD-810G
- ✓Altitude to 60,000ft: MIL-STD-29595
- ✓Explosive Decompression: MIL-STD-810G
- ✓Salt fog: MIL-STD-810G
- ✓Sand and Dust requirements: MIL-STD-810G

Additional Military Focus:

- ✓NATO **Standardized** Form Factors (i.e. 6T)
- ✓Maximized Power AND Energy density
- ✓Sustainability and Logistics issues
- ✓Silent Watch/Silent Mobility
- ✓On-board Electric Power

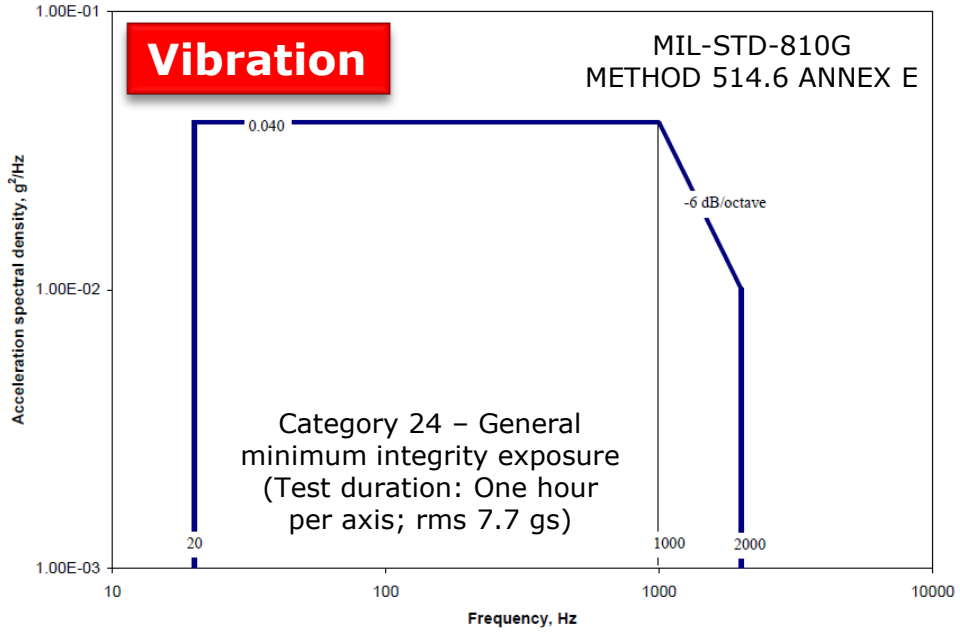
Commercial

Military

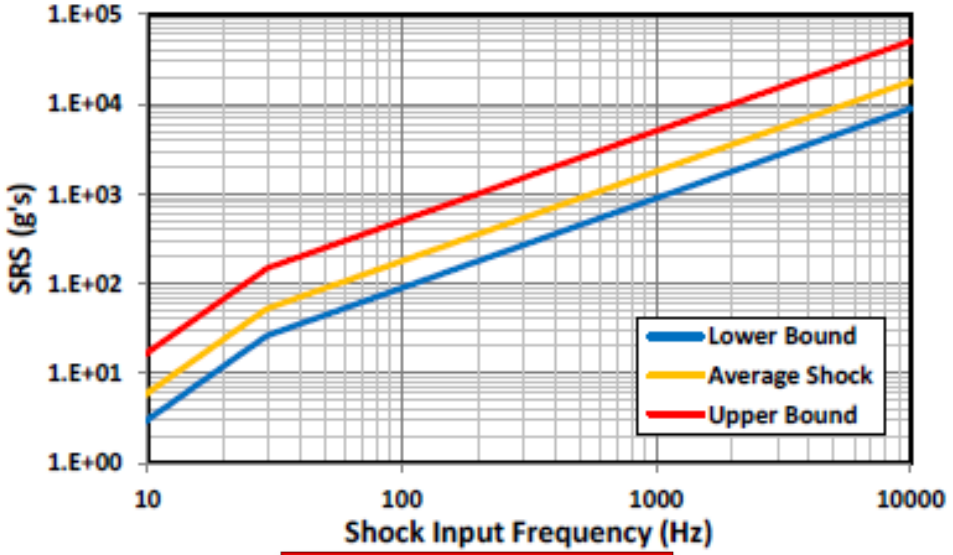
Standardized Military Batteries (i.e. 6T)
Used in 95% of Military Vehicles

Examples of Military Shock and Vibration Requirements

Vibration



MIL-STD-810G: Defines….



Ballistic Shock

Average Shock				Worst Case Shock		
Max. Resonant Freq. (Hz)[2]	Peak Displacement (mm)	Peak Velocity (m/s)	Peak Value of SRS[1] (g's)	Peak Displacement (mm)	Peak Velocity (m/s)	Peak Value of SRS[1] (g's)
10	15	1.0	6.0	42	2.8	17
29.5	15	3.0	52.5	42	8.5	148
100	15	3.0	178	42	8.5	502
1,000	15	3.0	1,780	42	8.5	5,020
10,000	15	3.0	17,800	42	8.5	50,200
100,000	15	3.0	178,000	42	8.5	502,000

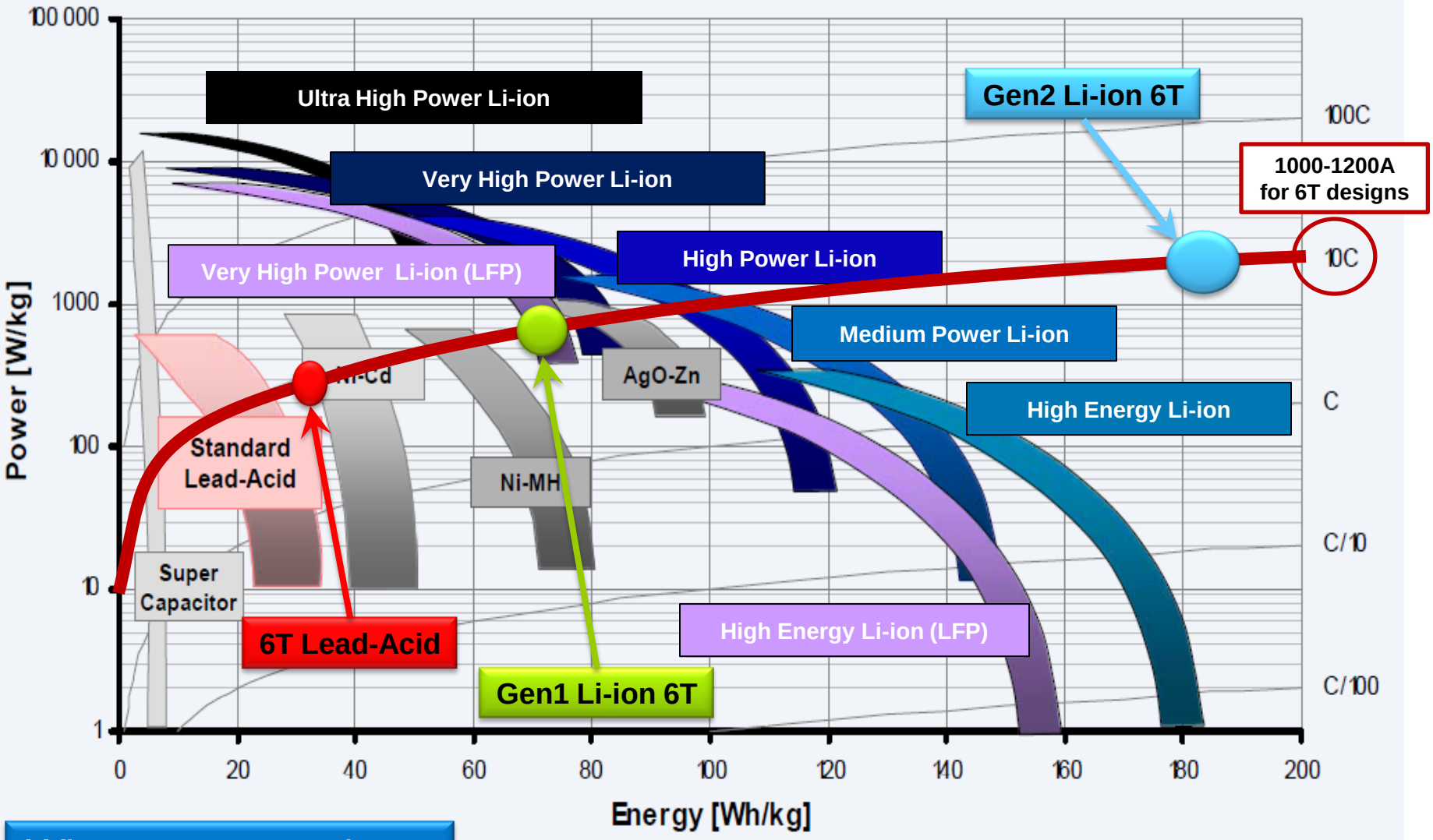
[1] SRS (Shock Response Spectrum) is Equivalent Static Acceleration for a damping ratio equal to 5 percent of critical.
[2] Tests involving all frequencies from 10 Hz to maximum frequency indicated.

Also need to consider…

Platform Specific Gunfire Shock:

~600g's for 3000Hz for some vehicles

Energy Storage Technology:
Ragone Plot (with Military Pack Targets)



Where are we today…

Battery Logistic Burden
(Importance of Battery Management for Current Systems)

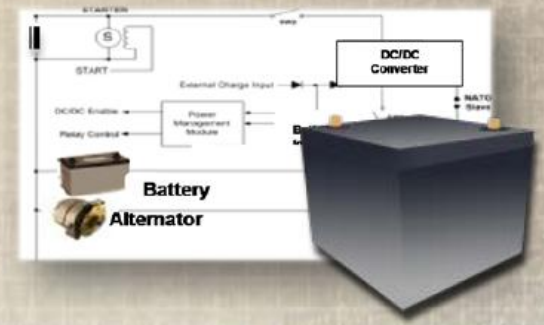
AGM Battery Failures 2002-2008	~5%
Incorrect Voltage Output	50%
Damaged - Transport Issues	30%
Improper Electrical Performance	20%

Approximately 80% of incorrect voltage failures were serviceable

Improved charging techniques can lead to 2X life improvement

Field Battery Maintenance & Training

Improved Charging



Battery Management

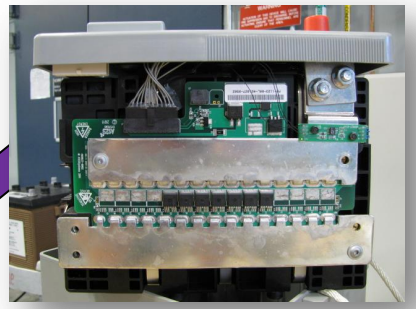
- Annual Purchase of Vehicle Batteries: 700,000

AGM = Absorbed Glass Mat ("Maintenance free")

Battery Management in Military Vehicles

Battery Monitoring System

The goal of any battery monitoring/management system is to be able to universally fit within all Army vehicles



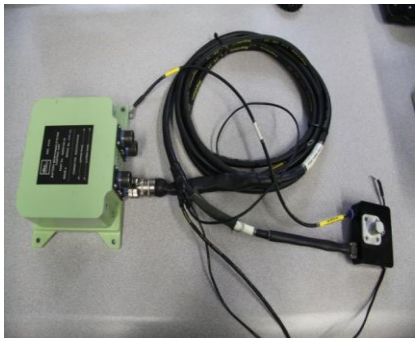
Advanced Chemistry Battery Management System

Battery Equalizer

Vehicle Power Control System

Battery Monitoring

Monitor: A monitoring system will measure cell/battery parameters, such as voltage, current, temperature and conductance (resistance), and provide an estimate for State of Charge (SOC), State of Health (SOH), and time remaining derived from these measurements. The acceptable accuracy range for these parameters is usually 5-10%, depending on the particular parameter. This information is then relayed to a user's display periodically. A monitor will not influence the power bus.



Battery Monitoring Systems

Lead Acid Batteries

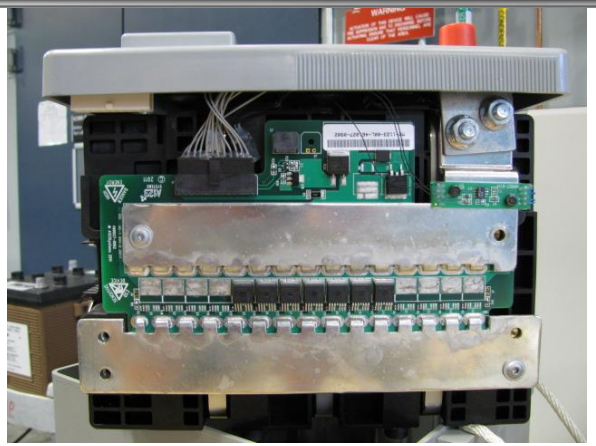
- The Battery Monitoring System used for lead acid batteries is a discrete system (installed separate from the batteries).
- Lead Acid Batteries are monitored at the module level (i.e. 12V 6T battery).

Li-Ion Batteries

- **The Battery Monitoring System is not typically used for Li-ion batteries as a stand alone system, but is instead integrated into the Li-ion battery itself.**
- **Li-ion batteries are monitored at the cell level.**
- **The monitoring is used in conjunction with higher management function**

Battery Management

Management: A management system will monitor battery parameters such as SOC, SOH, Voltage, Current, Temperature at the battery and/or cell level to detect usage conditions that could cause damage to the batteries or safety hazards. It will automatically intervene to prevent the battery from being operated in these unsafe or damage inducing conditions. This is to prevent failures such as overcharge, overdischarge, short-circuit and thermal runaway.



Integrated Battery Management System in a 6T Li-ion Battery

Lead Acid Batteries

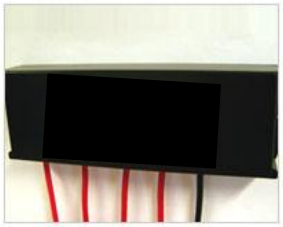
- The Battery Management System can be used for lead acid batteries.
- The Battery Management System is not as critical for Lead acid systems as compared to Li-ion, there is less risk of catastrophic failure without it.

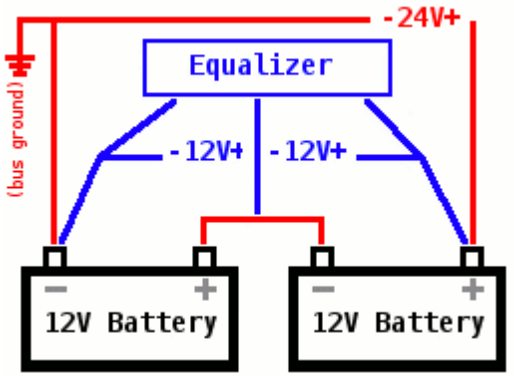
Li-Ion Batteries

- **The Battery Management System is vital for operation for Li-ion batteries**
- **The Battery Management System controls the charge and discharge of the cells within the battery module**
- **Without a management system, Li-ion cells can become unbalanced or operated in unsafe conditions, which could lead to catastrophic failure**

Battery Equalization/Balancing

Equalization: A battery equalizer will ensure that batteries and/or cells are charged and discharged with even state of charge to prevent an imbalance that can reduce battery life and reduce overall capacity. As batteries age, the SOC are unequal across the batteries, and the equalizer will help ensure balanced batteries. The equalizer can be part of a management system or stand alone.





Battery Equalizers

Lead Acid Batteries

- This is used with a Battery Monitoring System
- The Battery equalization system is used for Lead Acid batteries to evenly charge or discharge the 12V batteries that are connected in series
  - Some vehicles have a 12V tap
- This will lead to longer battery life

Li-Ion Batteries

- **The vehicle Li-ion batteries have a form of battery equalization**
- **This is integrated into the management system and provides balancing to individual cells.**

Battery Control

Battery Control: Battery control will facilitate battery charging and discharging in a vehicle with control strategies to optimize battery power usage and efficiency to improve overall vehicle performance.

Lead Acid Battery Control Unit

Lead Acid Batteries

- This is a complete power management system that provides charge control for the alternator to properly charge the energy storage system

Li-Ion Batteries

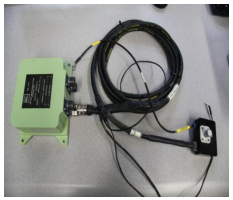
- **This is a complete power management system that provides charge control for the alternator to properly charge the energy storage system**

Lead Acid Battery Management Systems

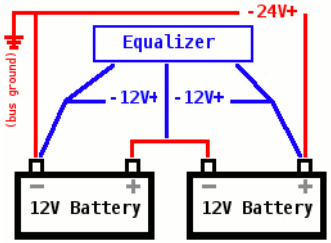
- **Battery Monitoring System**
  - Since 2009, TARDEC worked with PM Stryker, Abrams, Bradley, vehicle OEMs, and BMS vendors to develop BMS specification & ICD (ATPD-2406 & ATPD-2406A)
  - Evaluate commercial BMS as the Honest Broker for BMS technology
  - Provide in-house testing to be a unbiased qualifying source for PM
  - Without BMS, health of batteries is unknown and good batteries are being replaced.
    - Based on all samplings, ~80% AGM batteries turned in as unserviceable can be returned to service. (Source: AMSAA 6TAGM VRLA Battery Special Study 2011)

Evolution of Battery Monitoring/Management Systems

Current Battery Information is through warning lights, no vital information known



Battery Monitoring Systems provides Voltage, current, temperature, SoC, & SoH.



Battery Equalizers will keep battery SoC evenly balanced between pairs of batteries

Battery Management Systems will provide power management which may Include smart alternator charging

- **Payoffs**
  - ✓ **SoC, SoH, Indicator**
  - ✓ **Reduce logistics burden**
  - ✓ **SoC known in silent watch**
  - ✓ **Extension of battery life**
  - ✓ **Reducing maintenance costs**
  - ✓ **Reduce fuel consumption for battery charging**
  - ✓ **Optimize battery use during silent watch**

Li-ion Battery Standardization Design

- Li-ion battery has to work with existing vehicle electrical system
- Li-ion battery is sensitive to the battery overcharge and overdischarge – risks mitigated with integrated BMS
- 6T must support current force platforms (*no communication*) as well as next gen platforms (i.e. JLTV).

	# of Cells	1	3	4	6	7	8	n
NCA / NMC	Nominal Voltage(V) (NCA, NCM)	3.7	11.1	**14.8**	22.2	**25.9**	29.6	n x 3.7
	Voltage range (V) (NCA, NCM)	2.5-4.1	7.5-12.3	**10-16.4**	15-24.6	**17.5-28.7**	20-32.8	
LFP	Nominal Voltage(V) ($LiFePO_4$)	3.3	9.9	**13.2**	19.8	23.1	**26.4**	n x 3.3
	Voltage range (V) ($LiFePO_4$)	2.0-3.7	6-11.1	**8-14.8**	12-22.2	14-25.9	**16-29.6**	

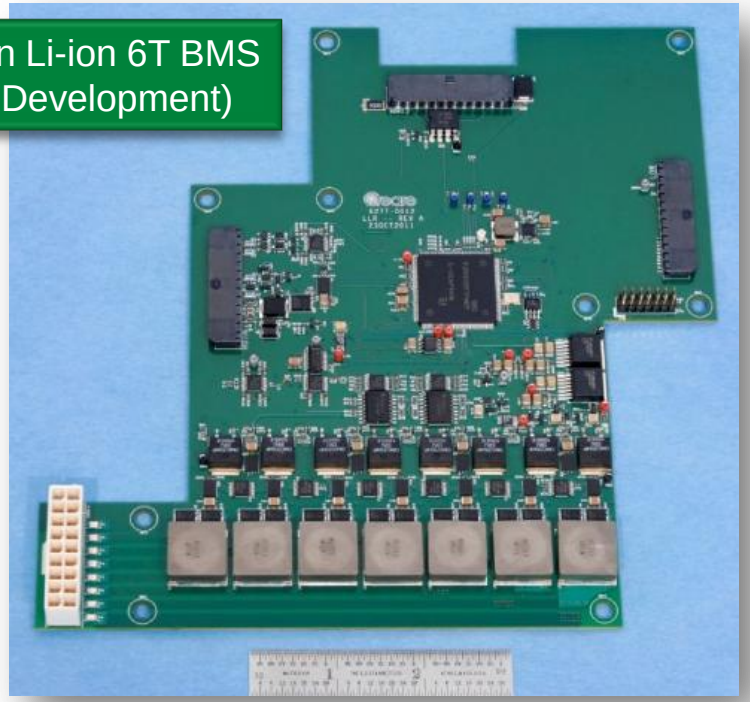
12V 6T

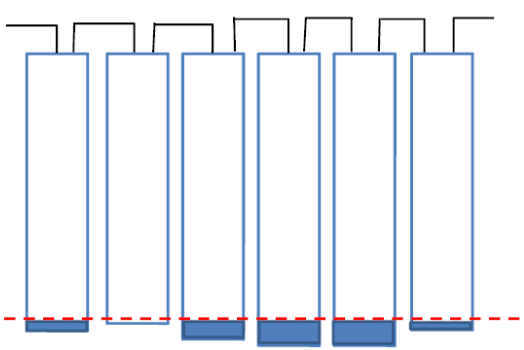
24V 6T

Advanced Chemistry BMS

- Required for Li-ion systems
  - Accommodates different Li-ion chemistries
- Monitors cell voltage and temperature
- Monitors SOC and SOH
  - Requires tighter tolerance than PbA (safety issue).
- Provides fault detection / protection
  - Overcharge
  - Overdischarge
  - Temperature limits
  - Overcurrent
  - Ground fault detection/ protection
- Provides communication to vehicle or platform.
- Potentially provides power limits based on SOC, SOH and temperature
- Controls thermal management system
- Meets EMI/Shock & Vib requirements
- Provides for cell balancing:

Common Li-ion 6T BMS
(SBIR Development)





TARDEC Lithium – Ion 6T Program

Accomplishments to date:

- Demo 2x increase in energy density
- Cut weight of each 6T in half (20kg vs. 40kg)
- Demo starting of HMMWV with single Gen1 24V battery (replacing 2 6TAGM)
- **Replaces 2 Lead Acid 6T batteries (@ 25% of weight!) 20kg (Li-ion) vs 80kg (Lead acid)**

12V Lead-Acid 6T Batteries
80kg total

24V Li-ion 6T Battery
Replaces 2 lead acid 6Ts
20kg

Commercial Platforms

Combat and Tactical Vehicles

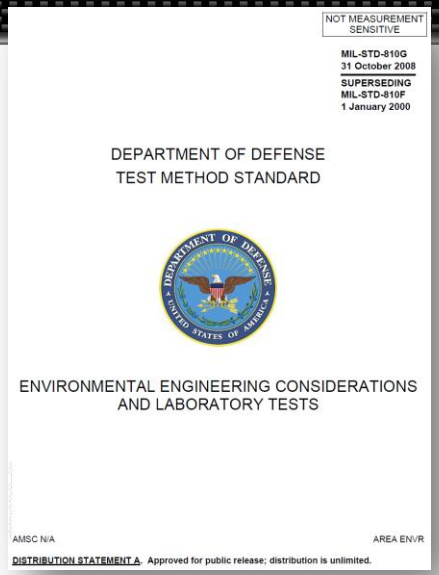
Army Watercraft Systems (AWS)

Purpose and Products:

- The 6T battery form factor is currently utilized in ~95% of the military ground vehicle platforms, therefore improvements with this technology would have widespread implications.
- TARDEC has developed prototype Generation 1 24-V 6T form-factor Lithium ion (Li-ion) batteries (Gen 1 6T) from two different manufacturers. A third supplier is under development.
- Gen 1 6T batteries are designed to be backward compatible such that they can be used as a direct replacement for currently used lead acid systems. Additionally, Gen 1 6T batteries provide the following benefits: reduced weight, reduced volume (2 for 1 replacement 24V vs. 12V), reduced logistics & sustainment burden, increased cycle life, and advanced battery management with state of charge and state of health indicators.
- TARDEC is also demonstrating the standardized batteries in support of anti-idling and start/stop applications for commercial truck and vehicle applications – to leverage commercial volumes and reliability (reduce costs).

Conclusions

- Military Vehicle have rigorous requirements for Battery Management Systems:
  - Extreme Shock and Vib. Requirements
  - EMI requirements
  - Operation in extreme environmental conditions (temperature / sand / dust)
  - Abuse Tolerance
- BMS are being developed for Lead acid systems in addition the Li-ion systems
  - Lead acid focus is improved performance and reliability
  - Li-ion focus on safety and performance
- Standardization needs to be the focus
  - Communication standards, Commonality and Interchangeability (minimize impact to ***EXISTING*** platforms!)
- Cost is important!
  - Leveraging and developing dual use technologies vital
  - Unlikely to transition without favorable ROI!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MIL-STD-810G
31 October 2008

SUPERSEDING
MIL-STD-810F
1 January 2000

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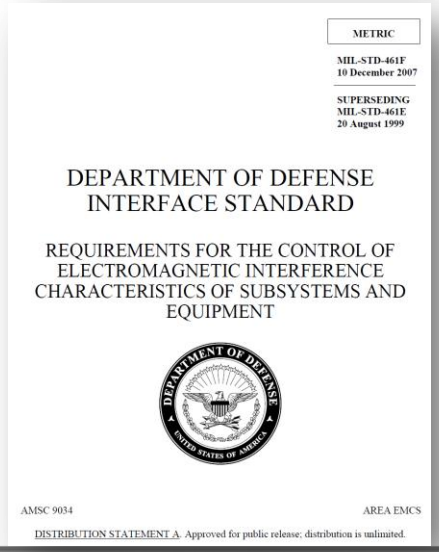
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